Solar Calibration of the EO-1 Advanced Land Imager

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***Abstract* – The solar calibration procedure for the EO-1 Advanced Land Imager (ALI) is described. Preliminary on-orbit results are presented and compared to the pre-launch calibration.**

INTRODUCTION

The first Earth-Observing satellite (EO-1) of NASA's New Millennium Program (NMP) was successfully launched on 21 November 2000. NMP missions are intended to flight validate advanced and innovative technologies. The primary instrument on EO-1 is an Advanced Land Imager (ALI) with multispectral imaging capability [1,2]. The Goddard Space Flight Center of NASA has overall responsibility for the EO-1 mission. MIT Lincoln Laboratory developed the Advanced Land Imager with NMP team members Raytheon Systems Santa Barbara Remote Sensing (SBRS) for the focal plane system and SSG Inc. for the optical system. Table 1 gives the mean wavelengths and bandwidths of the ten ALI spectral bands. The ALI employs a novel approach to solar calibration that enables radiometric calibration over the full range of expected earth radiances. This on-orbit solar calibration is one of four independent techniques being used to establish a high confidence radiometric calibration for the ALI [3]. The three other radiometric calibration techniques are the pre launch laboratory calibration, lunar scans, and measurements of well-characterized ground scenes [4,5,6]. Preliminary flight test results are described in [7].

TABLE 1
Summary of ALI spectral bands

ALI Bands	1p	1	2	PAN	3	4	4p	5p	5	7
Wavelength (nm)	442	485	567	592	660	790	866	1244	1640	2226
Bandwidth (nm)	19	53	70	144	56	31	44	88	171	272

SOLAR CALIBRATION TECHNIQUE

The solar calibration procedure, which is illustrated in Fig. 1, involves pointing the ALI at the sun with the aperture cover closed. A motor-driven aperture selector in the aperture cover assembly moves an opaque slide over a row of small to increasingly larger slit openings and then reverses the slide motion to block all sunlight. A series of seven discrete aperture areas can be obtained. Just prior to solar calibration, a space grade Spectralon® diffuser plate is swung over the secondary mirror by a motor-driven mechanism. The diffuser reflectively scatters the sunlight that would otherwise impinge on the secondary mirror. The scattered sunlight exposes the FPA to irradiance levels equivalent to earth-reflected sunlight for albedos ranging from 0 to 100%.

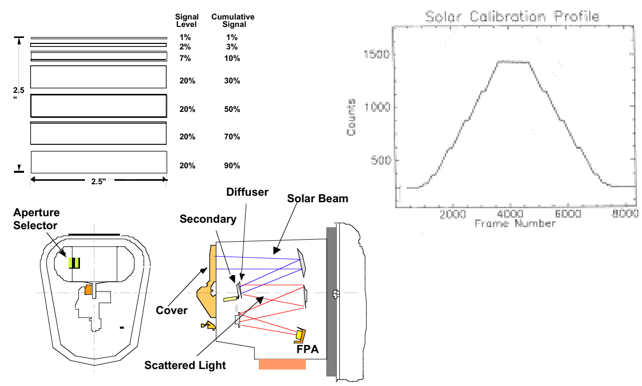

Fig. 1. Illustration of the solar calibration mode and laboratory test data from a solar simulator.

ANALYSIS

A detailed CODE V® optical analysis provided the ratios of the irradiance at the FPA to the solar irradiance at the sub aperture for each position of the aperture selector. For a given sub aperture the FPA irradiance was shown to vary by 2% over the full 15 degree field of view and by less than 1% over the region populated by detectors. During solar calibration the optical throughput differs from a normal data collection because the Spectralon BRDF replaces the reflectance of the secondary mirror. Measurements of the BRDF were made on a spare flight quality Spectralon disk over a spectral range of 400 to 900 nm and for the appropriate angles of incidence and reflection at NASA's Goddard Space Flight Center [8]. Values outside this spectral range were estimated by assuming that they scale as the total hemispherical reflectance, which was measured by Labsphere®. The resulting BRDF is shown in Fig. 2.

The irradiance at the FPA is thus a known function of the aperture slot opening and solar irradiance. This FPA irradiance corresponds to a known effective radiance at ALI entrance. The detector channel output corresponding to this effective radiance provides the solar calibration.

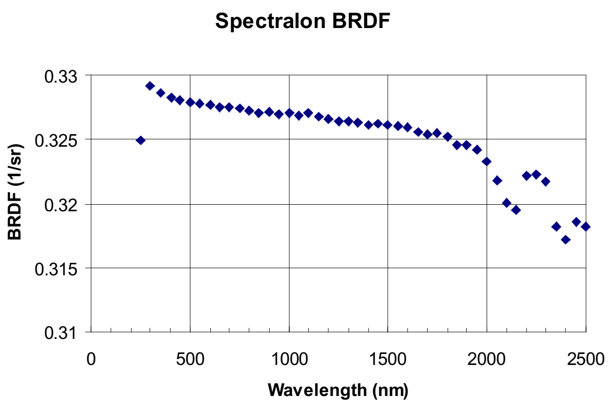

Fig. 2. BRDF of diffuser located in front of the ALI secondary mirror used in the solar calibration model.

Two solar irradiance models have been used in the analysis: the MODTRAN 4.0 – CHKUR model, which is currently being used for all Landsat 7 solar calibration derived gains [9], and the World Radiation Center (WRC) model. The solar irradiance correction factor (F) that is used to account for the varying earth sun distance is given by the approximation:

$$F = [\ 1+e\cos((d-4)360/365)]^2/[1-e^2\ ]^2$$

where d is the day of the year and e = 0.01671 is the eccentricity of the earth's orbit.

Finally the ALI must be pointed at the sun such that all of the sunlight coming through the sub aperture falls on the Spectralon. The calculated margin of error in the ALI pointing is 0.5 degrees. Half of this error tolerance was allocated to the spacecraft and half to the ALI alignment.

PRELIMINARY ON-ORBIT RESULTS

The detector response during a solar calibration sequence consists of an approximately linear increase as the aperture opens with a series of constant responses during those times when the slide passes over a reference bar. These bars provide a set of seven calibrated response points. When the aperture cover reverses direction and closes, the pattern of response reverses and proceeds back down to zero. Typical examples of detector responses for each of the ten ALI spectral bands are shown in Fig. 3.

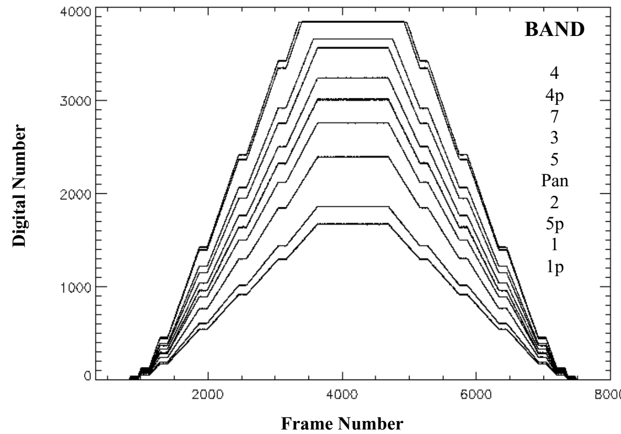

Fig. 3. Measured detector responses for the ten ALI bands during a solar calibration.

The flux level at the maximum or seventh level corresponds approximately to a 100% albedo at a 30 degree solar zenith angle. For the data shown, only bands 4 and 4p saturate at this maximum input level. The Estimated radiances using the pre-launch calibration for each band are normalized to the expected values from the solar model and are shown in Fig. 4. These data are plotted at the mean wavelength of the band. Results for two solar irradiance models are shown. Notice the significant differences between the two models in the SWIR region.

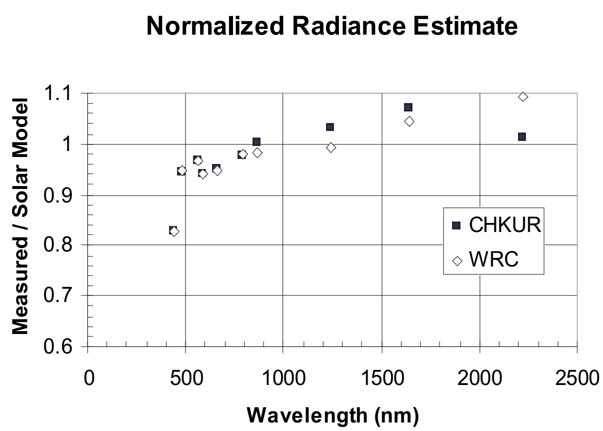

Fig. 4. Ratios of measured radiances to calculated radiances from the solar model.

DISCUSSION

With the exception of band 1p, the solar and pre-launch calibrations agree to within the estimated uncertainties of the two independent techniques. The pre-launch calibration accuracy combined with the additional on-orbit effects of contamination and stray light [7] is currently estimated to be less than 5% for all bands. The solar calibration uncertainty is currently estimated to be 5% in the VNIR bands and 7% in the SWIR bands. The larger uncertainty in the SWIR bands is due to both the uncertainty in the solar irradiance models and the BRDF of the Spectralon. The low response in band 1p is a significant discrepancy between the two calibration techniques. Flight data from the internal reference lamps [7] indicate that the on-orbit response of the FPA is consistent with the pre-launch calibration. A potential cause for this result could be degradation of the Spectralon diffuser which is known to be highly susceptible to contamination. This discrepancy will be resolved by comparing solar calibration results to two other calibration techniques, i.e., radiometric lunar calibration and measurements of well-characterized ground scenes. The solar calibration data exhibit two other interesting trends which are of lesser significance. There is a general increase in the ratios with increasing wavelength as can be seen in Fig. 4. A second effect, not shown here, is a decrease in the ratio with decreasing aperture area. The effect is highly suggestive of a vignetting of the beam, i.e., it is not completely on the Spectralon or a systematic error (within machining tolerances) in the aperture areas.

WORK IN PROGRESS

The major focus of activity is the resolution of the band 1p discrepancy. Flight data for both lunar calibration and well-characterized ground scenes have been taken and are currently being analyzed. The slight decrease in the ratios with decreasing wavelength, and aperture area are being reviewed in order to improve the overall accuracy of the solar calibration procedure. As of this writing, a total of six solar calibration measurements have been made. About four were made with known pointing error offsets. The last two were made with all spacecraft pointing errors removed. These data are being analyzed to establish both the sensitivity to pointing errors and the stability of the process with constant pointing. The vignetting hypothesis will be tested with a special sequence of solar calibrations where the pointing is systematically changed so that the response as a function on pointing can be mapped out.

CONCLUSION

Initial results of the EO-1 ALI solar calibration have demonstrated that the ALI diffuser and aperture selector mechanisms worked well and data collection was nominal. The solar calibration covers the full range of expected earth radiance values from 0 to 100% albedos. With the exception of band 1p there was good overall agreement with ground calibration. The band 1p discrepancy should be resolved by ongoing analysis of data from lunar calibration and measurements of well-characterized ground scenes. Other smaller discrepancies are being reviewed to improve the overall accuracy of this technique.

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